Evaluating RF Exposure of Amateur Radio Stations

How Radio Amateurs Evaluate Human Exposure from their Stations

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FCC Human Exposure Rules

- Originally released in 1996
- Radio amateurs were introduced to human exposure limits for the first time
- ARRL published RF Exposure and You
- Minor rule changes were made in 2013
- New rule changes were published in the April 1, 2020 Federal Register
- New rules were supposed to take effect June 1, 2020, but are on hold pending the review process

Human Exposure Rules Basis

IEEE Std C95.1™-2019
(Revision of
IEEE Std C95.1-2005/
Incorporates IEEE Std C95.1-2019/Cor 1-2019)

IEEE Standard for Safety Levels with Respect to Human Exposure to Electric, Magnetic, and Electromagnetic Fields, 0 Hz to 300 GHz

Developed by the

IEEE International Committee on Electromagnetic Safety

Approved 8 February 2019

What Will Change

- Amateurs will no longer have categorical exclusions to evaluation
- New exemptions to routine evaluation will be based on frequency, power and distance
- All transmitters that are within 20 cm of the body must be evaluated with Specific Absorption Rate (SAR)
- SAR modeling is accepted in addition to SAR testing

Assumptions

- Maximum Permissible Exposure (MPE) limits are based on IEEE STD C95.1-2019
- SAR limits are the same:
  - 0.4 W/Kg averaged over the whole body
  - 8 W/Kg averaged over any 1 gram of tissue
  - 20 W/Kg averaged over 10 grams of tissue in the hands, wrists, feet and ankles
- Hams and their families are considered to be in the Controlled Exposure category
- All hams should perform their own exposure analyses and have it available if asked.
- You do not have to submit results to the FCC unless asked (but count on being asked if anyone complains about your station to the FCC)
- You should keep your analysis updated with new modes, radios and antennas.

Specific Absorption Rate (SAR) Definition

- The time derivative of the incremental energy (dW) absorbed by (dissipated in) an incremental mass (dm) contained in a volume element (dV) of given density (ρ).
- SAR is expressed by the unit of watt per kilogram (W/kg).

$$SAR = \frac{d}{dt}\left(\frac{dW}{dm}\right) = \frac{d}{dt}\left(\frac{dW}{\rho dV}\right)$$

From IEEE Std C95.7-2014

- In other words, it is a measure of how quickly the body can dissipate heat that is absorbed from incident RF power.

More Definitions

- The MPE limits are primarily aimed at laboratory, military, and commercial RF-based installations such as communication centers and broadcast stations.
- Controlled environment
  - An area where the occupancy and activity of those within is subject to control for the purpose of protection from RF exposure hazards.
- Uncontrolled environment
  - The preferred term is “general public exposure.”
  - Any area other than a controlled environment.
  - The uncontrolled environment includes locations where persons are not made fully aware of the potential for exposure by the owner, operator, or party responsible for the source or cannot exercise control over their exposure.

Analysis Process

- The following slides show how to perform an RF exposure analysis of your station.
- Relatively easy process
- Once completed, it only needs updating if you add a new antenna or operating frequency range
- Some basic math skills are required.
  - Addition and subtraction
  - Multiplication and division
  - Converting linear to dB, which uses logarithms and exponentiation

MPE Tables from IEEE Std C95.1 2019

f = Frequency in MHz

- Uncontrolled environment

Frequency range (MHz)	Electric field strength (E) (V/m)	Magnetic field strength (H) (A/m)	Power density (S) (W/m^2)	Averaging time (min)
1.34 to 30	$823.8 / f$	$16.3 / f$	$13428 / f^2$	30
30 to 100	27.5	$158.3 / f^{1.668}$	$4353 / f^{1.668}$	30
100 to 400	27.5	0.0729	2	30
400 to 2000	—	—	$f / 200$	30

- Controlled environment

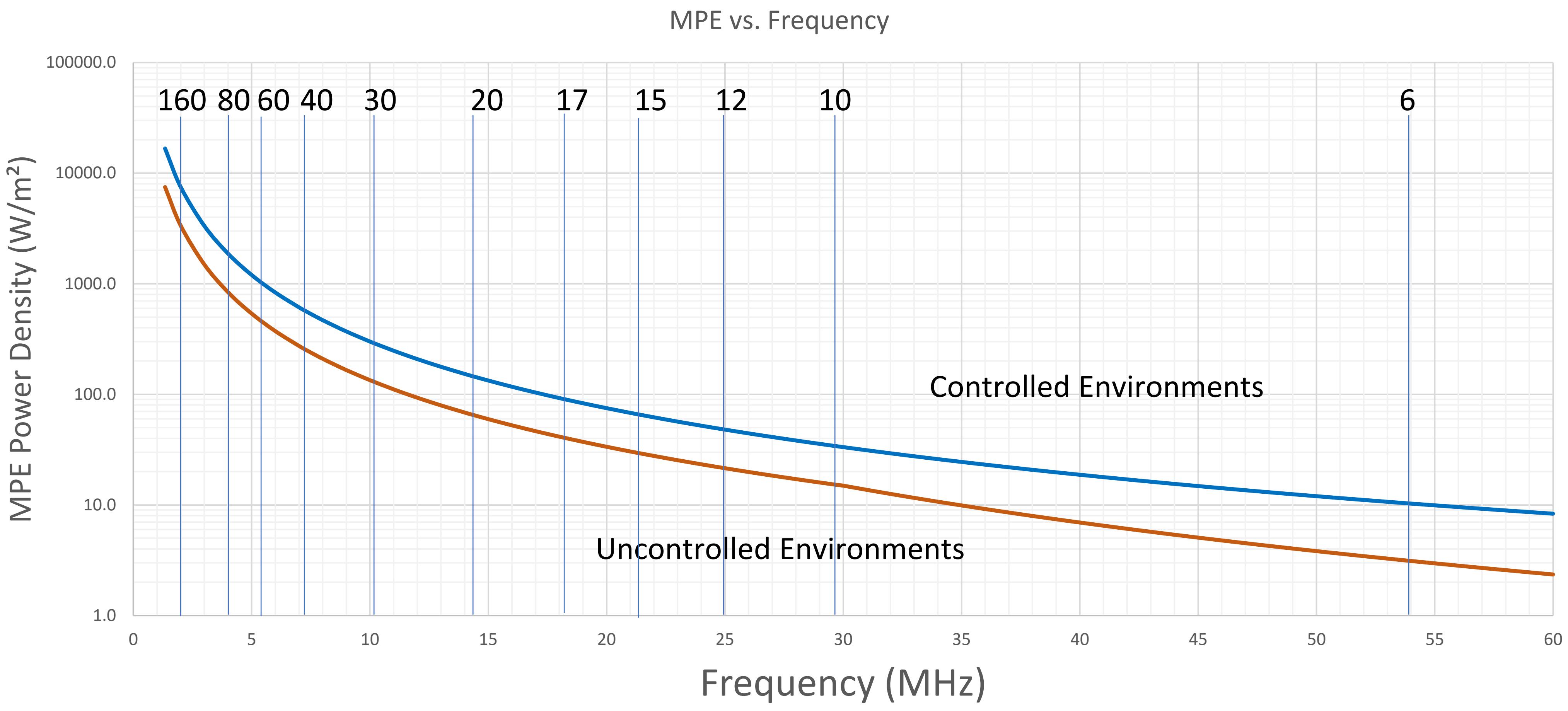
Frequency range (MHz)	Electric field strength (E) (V/m)	Magnetic field strength (H) (A/m)	Power density (S) (W/m^2)	Averaging time (min)
1.0 to 30	$1842 / f$	$16.3 / f$	$30{,}000 / f^2$	30
30 to 100	61.4	$16.3 / f$	$1000 / f$	30
100 to 400	61.4	0.163	10	30
400 to 2000	—	—	$f / 40$	30

Amateur Band MPE Limits

- Limits are calculated from the table on the previous slide.
- All limits are in W/m^2

Band	Uncontrolled	Controlled
160	3357	7500
80	839	1875
60	373	833
40	252	563
30	132	294
20	65.2	246
17	41	91
15	29.2	65.2
12	21.5	48
10	15.2	34
6	3.1	10.3

MPE Chart


MPE vs. Frequency
100000.0
10000.0
1000.0
100.0
10.0
1.0
MPE Power Density (W/m²)
160
80
60
40
30
20
17
15
12
10
6
Controlled Environments
Uncontrolled Environments
0
5
10
15
20
25
30
35
40
45
50
55
60
Frequency (MHz)

Exemption Criteria

- Exemption means that a particular frequency/power/antenna combination does not require further evaluation
  - It is a good idea to make the calculations on the exempt situations anyway for completeness
- The new exemptions will be based on three things:
  - Frequency
  - Maximum ERP (taking into account antenna gain) for a particular antenna
  - Distance between a person and *any radiating part* of the antenna
- Exemptions do not apply to distances less than $\lambda/2\pi$
- If both criteria in the following slides are met, then you do not need to make additional calculations on that particular frequency/power/antenna combination.

Exemption Criteria 1

- RF Environmental Evaluation must be performed if *any person* at *any* time will be closer than *R* meters to *any radiating part* of the antenna *and* the ERP exceeds the values calculated from the following table:

Frequency (MHz)	Threshold ERP (watts)
0.3-1.34	1920 R^2
1.34-30	3450 R^2 / f^2
30-300	3.83 R^2
300-1500	0.0128 $R^2 f$
1500-100000	19.2 R^2

f is in MHz
R is in meters and must be greater than $\lambda/2\pi$ (see next slide)

Exemption Criteria 2

- Exemptions can only be taken if the distance between the antenna and a human is greater than these distances (λ/2π):

160 m (1.8 – 2.0 MHz)	82.8 feet
80 m (3.5 – 3.75 MHz)	41.3 feet
75 m (3.75 – 4.0 MHz)	38.8 feet
60 m (5.22 – 5.41 MHz)	29.6 feet
40 m (7.0 – 7.3 MHz)	20.7 feet
30 m (10.1 – 10.15 MHz)	15.5 feet
20 m (14.0 – 14.35 MHz)	10.3 feet
17 m (18.068 – 18.168 MHz)	8.8 feet
15 m (21.0 – 21.45 MHz)	7.8 feet

12 m (24.89 – 24.99 MHz)	6.2 feet
10 m (28.0 – 29.7 MHz)	5.2 feet
6 m (50 – 54 MHz)	3.1 feet
2 m (140 – 144 MHz)	1.0 foot
1.25 m (222 – 225 MHz)	7.8 inches
For higher frequencies, λ/2π is less than 20 cm (7.8 inches) SAR exemption or testing is required	
70 cm (420 – 450 MHz)	4.3 inches
33 cm (902 – 928 MHz)	2.0 inches

Mobile and Hand-held Radios

- All mobile radios were previously “Categorically Excluded” for hams
- That included handheld radios that are held next to the head
- The new exemptions will be based on distance from the antenna to the body
- Anything less than 20 cm (~ 8 inches) must be measured or calculated with SAR
- SAR is very complicated to either measure or calculate
- The SAR exemptions are only valid for frequencies above 300 MHz

Don’t Panic

- Follow the process
- I will use my home station as an example
  - Step 1 Determine antenna-to-human distance
  - Step 2 Calculate ERP
    - ERP is a function of RF power and antenna gain relative to a λ/2 dipole
    - Averaged over 30 minutes
    - Considers modulation type
    - Based on actual transmitter “on” times
  - Step 3 Make an exemption table
  - Step 4 Calculate power density for non-exempt combinations
  - Step 5 Summarize

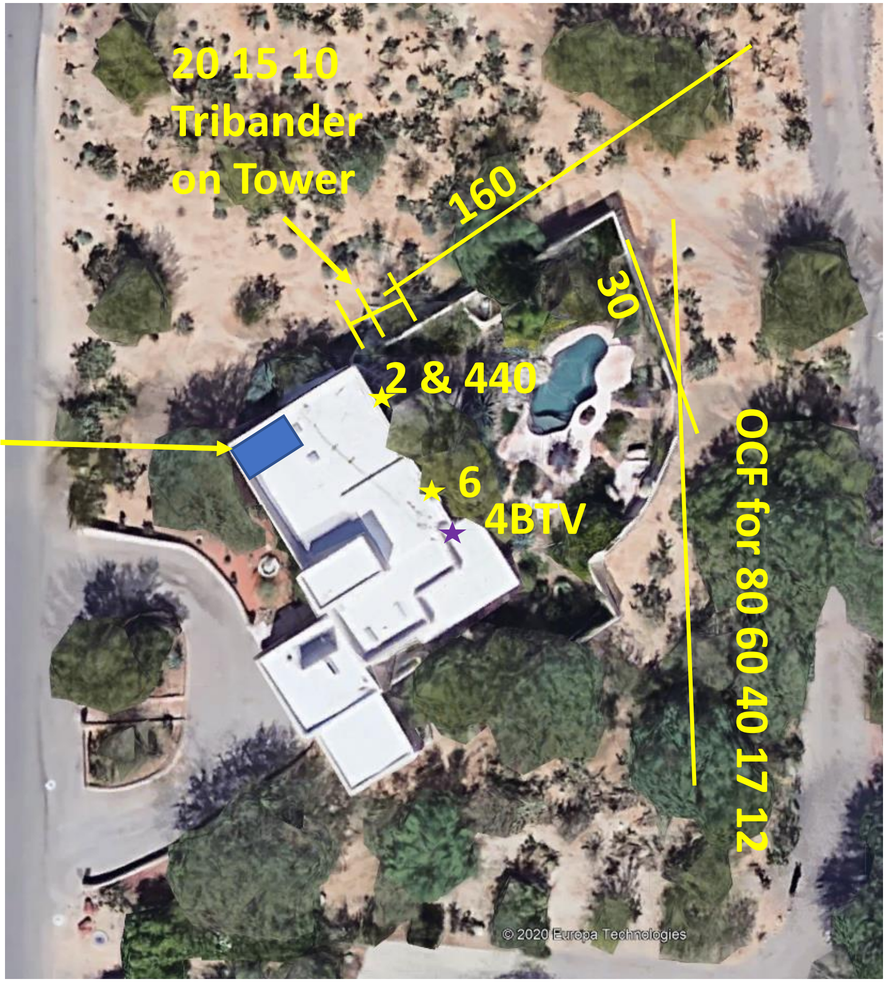
Home Station Antenna Layout

80 feet from tower and 160 antenna to neighboring house

The tri-bander is 21 feet high when the tower is all the way down (worst case)

Shack Location

The bases of the 6-meter, VHF, and UHF antennas are 17 feet off the ground



The 30 meter antenna is 10 feet high

The 80 – 12 antenna is 20 feet high

The 4BTV base is 17 feet off the ground
Only transmit on 10 meters with 4BTV

90 feet to neighboring house

85 feet from south tip of OCF to neighboring house

Antenna-to-Human Distances & Gain

Note: These distances are for determining exposure

Antenna	Bands	Uncontrolled Distance (feet)	Gain in the Direction of Uncontrolled (dBd)	Controlled Distance (feet)	Gain in the Direction of Controlled (dBd)
160 Inv L	160	88	0	39	-2
OCF dipole	80, 60, 40, 17, 12	85	-3	18	0
30 m dipole	30	118	-3	17	0
Tri-band Yagi	20, 15, 10	107	-3	33	-10
6 m Vert	6	156	+5	10	-10
2 m Vert	2	128	+4	11	-15
70 cm Vert	70 cm	128	+2.8	11	-15
4BTV	10	153	-0	10	-10

Step 2 – Calculate ERP

- Start with peak RF transmitter power
- Account for losses in dB
  - Convert to linear
  - Linear loss factor = $10^{-(dB/10)}$
- Antenna gain in the direction of interest (dBd)
  - Linear gain = $10^{(dBd/10)}$
- Figure duty factor
  - Modulation type
  - Operating habits

Calculate Peak ERP

- Peak ERP is a function of the following
- Peak RF Power at the antenna feed point
  - Transmitter power less all losses between the transmitter output and the antenna feed point
  - Transmission Line loss = loss per 100 feet * length / 100
  - Connector loss of PL259 is approximately 0.05 dB
  - Use manufacturer loss values for baluns, line isolation transformers, and anything else in the transmit path.
- The gain of the antenna relative to a half-wave dipole
  - For RF exposure calculations, the gain used is the gain in the direction to the point of interest from the radiation center of the antenna relative to a dipole
  - For exclusion calculations use the peak gain

Sample Feed Point Power Calculation

- This example is 160 meters (2 MHz)
- Cable loss (RG-213): 0.212dB/100 feet x 60 feet = 0.127 dB
- Connector losses (PL-259): 4 at 0.05 dB each = 0.20 dB
- Combined Balun & Line Isolator loss = 0.07 dB
- Total losses = 0.397 dB
- Convert to linear: $10^{(-0.397/10)} = 0.913$
  - Note that losses are negative dB values when converting to linear
- Multiply by the peak RF power (1000 watts) = 913 watts

Time Averaging

- The final exposure value is the incident peak RF field power density averaged over 30 minutes
- Three parameters determine how much to reduce the peak power to derive the average power
  - Modulation type (next slide)
  - Transmit duty factor based on usage (next slide)
  - Another averaging function is how much time in 30 minutes someone in the area would spend while being subjected to the RF field if that time is less than 30 minutes.

Transmit Duty Factor

- The following table shows common transmit duty factor values
- Tailor your values to your operating habits – these are mine
- Apply the 30-minute average duty factors to the ERP calculations
- Duty factors are often different for each band

Mode	Instantaneous	Average over 30 minutes	Final 30-minute Average
Conversational SSB	20%	Rag chewing, casual net: 10%	0.02
Processed SSB	50%	Chasing DX: 5%	0.01 (4 each 3-sec per min)
		Contest Running 25%, S&P 10%	0.05 (I only S&P)
CW	40%	20% or less	0.08
RTTY	100%	Contesting: 25%, Casual operating: 10%	0.25
AM	100%	Conversational: 10%	0.1 (6m only)
FM	100%	Conversational: 10%	0.1 (2m and 70 cm only)
Digital Modes	100%	FT8 constant CQ: 40% 2 mins on, 2 mins off	0.2 (6m and 160m only)
		FT8 S&P: 5%	0.05 (6m and 160m only)

Calculate Average ERP (1 of 2)

Parameter	160	OCF	OCF	OCF	OCF	OCF	30	4BTV	6 Vert	2Vert	70 Vert
Band	160	80	60	40	17	12	30	10	6	2	.7
Transmit Power (w)	1000	1000	100	1000	1000	1000	275	1000	100	50	50
Total Losses (dB)	0.47	1.12	1.15	1.52	1.72	1.92	1.73	0.95	0.88	1.55	2.39
Peak Power at Antenna Feed Point	913	773	77	705	673	643	185	804	81.7	35.0	28.8
Final Average	0.08	0.25	0.05	0.25	0.08	0.01	0.2	0.02	0.2	0.1	0.1
Gain (dBd)	0	0	0	0	0	0	0	0	+5	+4	+5
Net Ave ERP	73.0	193	3.85	176	53.8	6.43	37	16.1	51.7	8.79	9.11

Calculate Average ERP (2 of 2)

Parameter	Yagi	Yagi	Yagi
Band	20	15	10
Transmit Power (w)	1000	1000	1000
Total Losses (dB)	0.8	0.91	1.07
Peak Power at Antenna Feed Point	831	811	782
Duty Factor	0.25	0.25	0.25
Gain (dBd)	4.4	4.8	5.2
Net Ave ERP	572	612	647

Step 3 – Make an Exemption Table

Band	Exempt Distance	Actual Distance (min)	Thres-hold ERP	Actual Avg ERP
160 m	82.8 feet	39	15705	73.0
80 m	38.8 feet	18	3926	193
60 m	29.6 feet	18	2146	3.85
40 m	20.7 feet	18	1179	176
30 m	15.5 feet	17	700	37
20 m	10.3 feet	33	948	572
17 m	8.8 feet	18	190	53.8
15 m	7.8 feet	33	435	612

Band	Exempt Distance	Actual Distance (min)	Thres-hold ERP	Actual Avg ERP
12 m	6.2 feet	18	101	6.43
10 m	5.2 feet	10	36.3	16.1
6 m	3.1 feet	10	35.6	51.7
2 m	1.0 foot	11	43.1	8.79
1.25 m	7.8 inches			
70 cm	4.3 inches	11 feet	64.7	9.11
33 cm	2.0 inches			--

- Note that the distances are to the closest radiating part of the antenna, not the center of radiation
- All double-green antenna/RF power combinations meet both criteria and are exempt from further analysis

Step 4 – Calculate Power Density

- Calculations are needed for all non-exempt frequency/antenna combinations
- Power density is a function of the following
  - Average RF power at the antenna feed point
  - Antenna gain in the direction of where people could be
  - Distance from the antenna to where people could be

Power Density Calculations

- S = power density in watts/m²
- P = power at the antenna feed point
- G = antenna gain relative to a dipole in the direction of people
  - In linear terms, not dB   [linear = $10^{(\text{gain in dBd}/10)}$]
  - 1.59 is the ratio of the gain of a dipole relative to an isotropic antenna
    - The power density equation is based on an isotropic radiator
  - $4\,\pi\,R^2$ is the surface area of a sphere with a radius of R
- R = distance from the antenna radiation center to the location of people

$$S = \frac{P\,G}{1.59 \cdot 4\,\pi\,R^2}$$

Power Density Table - Uncontrolled

Antenna	Average Power (W)	Gain in direction of interest	Uncontrolled Distance		Power Density W/m²	Power Density Limit W/m²	Margin
160	73.0	0 dBd	88 ft	26.8 m	5.08×10^{-3}	3357	58.2 dB
80	193	0 dBd	85 ft	25.9 m	14.39×10^{-3}	1875	51.2 dB
60	3.85	0 dBd	85 ft	25.9 m	0.29×10^{-3}	833	64.6 dB
40	176	0 dBd	85 ft	25.9 m	13.12×10^{-3}	563	46.3 dB
6	51.7	+2.8 dBd	156 ft	47.6 m	2.18×10^{-3}	294	51.3 dB

In this case no mitigation is needed

Power Density Table - Controlled

Antenna	Average Power (W)	Gain in direction of interest	Controlled Distance		Power Density W/m²	Power Density Limit W/m²	Margin
160	73.0	0 dBd	39 ft	11.9 m	3.20×10^{-3}	7500	63.7 dB
80	193	0 dBd	18 ft	5.49 m	14.39×10^{-3}	1875	51.2 dB
60	3.85	0 dBd	18 ft	5.49 m	0.29×10^{-3}	833	64.6 dB
40	176	0 dBd	18 ft	5.49 m	13.12×10^{-3}	563	46.3 dB
6	51.7	-10 dBd	10 ft	3.05 m	0.11×10^{-3}	294	64.3 dB

In this case no mitigation is needed

Step 5 – Analyze

- Determine if the power density where people will be is greater than the allowable threshold
- If the threshold is exceeded on any band, then decide on a mitigation plan and execute the plan
  - Limiting RF power
  - Moving antennas
  - Blocking access to the antenna area

Power Density Compliance

- In this case all antenna/transmitter combinations are compliant with the requirements